



Astable Oscillator Circuits Using Silicon-on-Insulator Timer Chip for Wide Range Temperature Sensing

Richard L. Patterson
Glenn Research Center, Cleveland, Ohio

Ahmad Hammoud
ASRC Aerospace Corporation, Cleveland, Ohio

Malik Elbuluk
University of Akron, Akron, Ohio

Dennis Culley
Glenn Research Center, Cleveland, Ohio

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Malik Elbuluk

University of Akron

Akron, Ohio 44325

Dennis Culley

National Aeronautics and Space Administration

Glenn Research Center

Cleveland, Ohio 44135

Abstract

Two astable oscillator circuits were constructed using a new silicon-on-insulator (SOI) 555 timer chip (ref. 1) for potential use as a temperature sensor in harsh environments encompassing jet engine and space mission applications. The two circuits, which differed slightly in configuration, were evaluated between –190 and 200 °C. The output of each circuit was made to produce a stream of rectangular pulses whose frequency was proportional to the sensed temperature. The preliminary results indicated that both circuits performed relatively well over the entire test temperature range. In addition, after the circuits were subjected to limited thermal cycling over the temperature range of –190 to 200 °C, the performance of either circuit did not experience any significant change.

Temperature Sensor Circuits

Each astable oscillator circuit was constructed using a high temperature polyimide circuit board, Teflon-coated wires, and high temperature lead-free solder. A recently-introduced high temperature silicon-on-insulator (SOI) precision 555 timer comprised the main element of each circuit. The CISSOID CHT-555-DIL14 ceramic-packaged timer chip was specified for –30 to 225 °C operation (ref. 1). The other components in each circuit included a high temperature precision, thin film platinum RTD (Resistance Temperature Detector) as the temperature-sensing element, a film power resistor, a solid tantalum input filter capacitor, and two ceramic capacitors. A photograph of one of the assembled circuit boards is shown in figure 1. The two circuits differed slightly in their wiring configuration, and some of the individual parts had different values. A schematic of the basic astable circuit (Circuit 1) is shown in figure 2, and that of a modified astable oscillator (Circuit 2) is shown in figure 3.

As was mentioned earlier, the main distinction between the two oscillator circuits included the way the bias resistor and the RTD were connected in the circuit, as seen in figures 2 and 3. The other dissimilarities included the values used for the bias resistor (R1) and the timing capacitor (C1). While a 2 kΩ resistor and a 0.1 μf capacitor were used in Circuit 1, the other circuit utilized a 10 kΩ and a 0.01 μf for these respective parts. This was done intentionally so that different ranges in output frequency were obtained. The two oscillator circuits were evaluated at selected test temperatures between –190 to 200 °C.

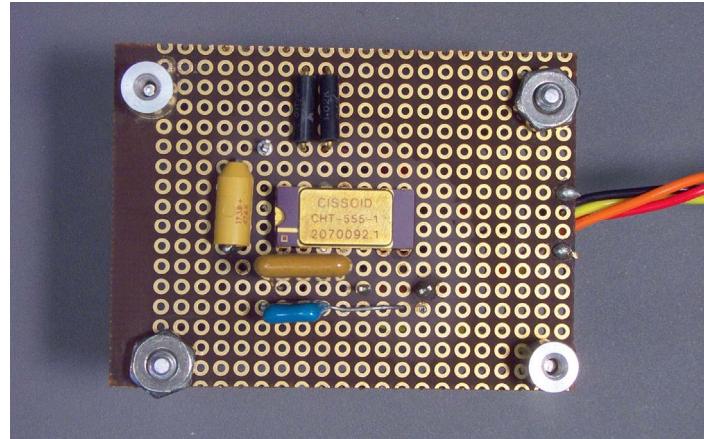


Figure 1.—Astable oscillator circuit board using the CHT-555-DIL14 timer.

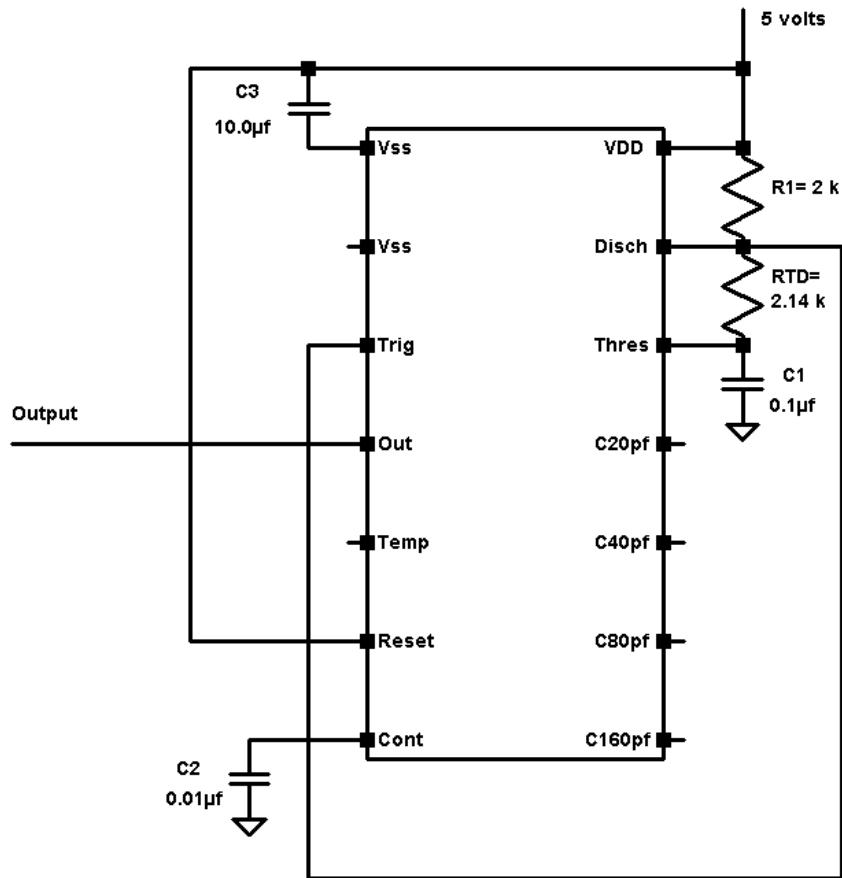


Figure 2.—Schematic of the astable oscillator circuit (Circuit 1).

The effect of thermal cycling was also investigated by subjecting the circuits to a total of ten cycles each between 200 and -190°C . A temperature rate of change of $10^{\circ}\text{C}/\text{min}$ and a dwell time of 10 minutes at test temperature were used in these investigations. The circuits were evaluated in terms of frequency-to-temperature conversion, period-to-temperature conversion, output signal duty cycle, and supply current under extreme temperatures and wide thermal cycling.

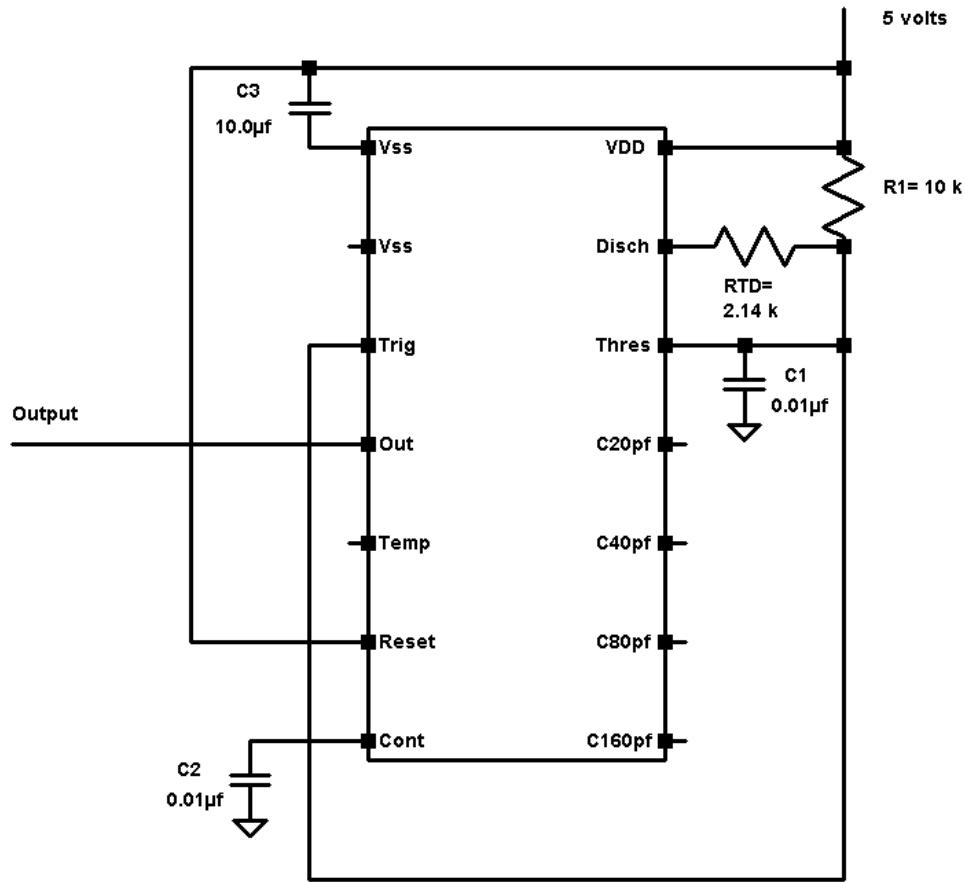
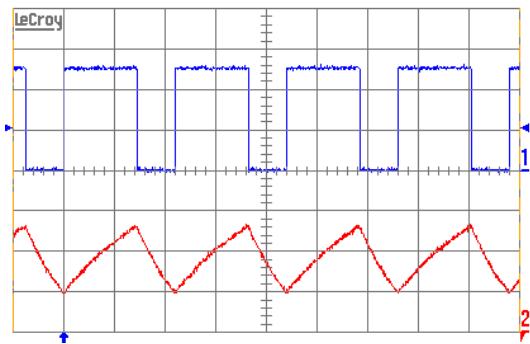


Figure 3.—Schematic of the modified astable oscillator circuit (Circuit 2).

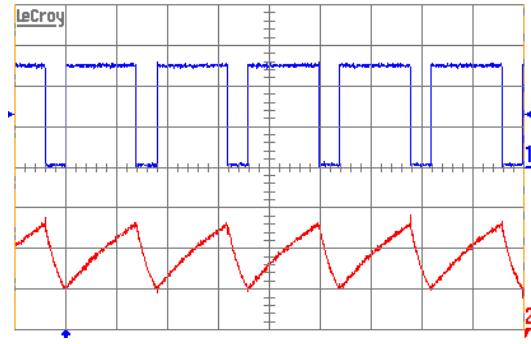
Results

A typical output response of the two astable temperature-to-frequency conversion circuits, which comprised of a rectangular pulse train (blue signal), is shown in figure 4. The signal at the threshold pin (magenta), which governs the charge/discharge cycle of the timing capacitor C1, is also depicted in this figure as a triangular waveform. These waveforms, which were obtained prior to thermal cycling, were taken at 25 °C as well as at the extreme test temperatures 200 and –195 °C. It can be seen that both oscillator circuits performed very well throughout the temperature range from 200 to –190 °C as the frequency of the output signal fluctuated with variation in the sensed temperature. While the frequency of the output signal of Circuit 1 had a value of about 2.222 kHz at room temperature, it decreased to about 1.575 kHz at 200 °C, and it increased to a value of 4.649 kHz when the temperature approached –190 °C. Similarly, the output of Circuit 2 exhibited a frequency of 11.147 kHz at room temperature, dropped to 8.841 kHz at 200 °C, and increased to 12.922 kHz at –190 °C. This variation in output frequency with sensed temperature for both circuits is shown in figure 5.

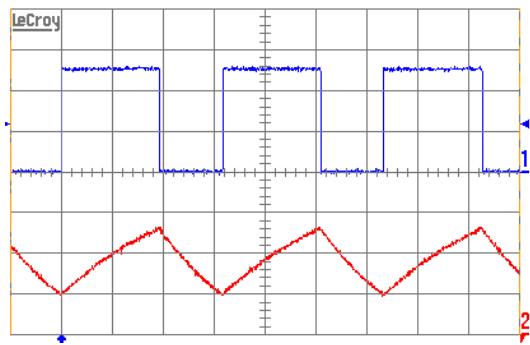
Figure 6 shows the period of the output signal of both circuits as a function of temperature. In general, the period of the output in either circuit experienced a gradual increase as the test temperature changed from cryogenic to hot. The increase in the period of the output signal of Circuit 1, however, was much more linear than Circuit 2. Both circuits experienced an increase in the duty cycle of the output signal as the test temperature was made cooler, and the duty cycle decreased as temperatures went above room temperature, as shown in figure 7. For example, it increased to about 84 and 95 percent for Circuit 1 and Circuit 2, respectively, at the cryogenic temperature of –190 °C, and it approached 60 percent at 200 °C for either circuit. As far as the supply current was concerned, both circuits exhibited minimal increase as test temperature was increased, as shown in figure 8.



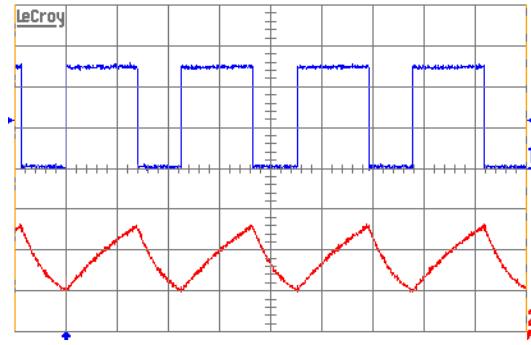
Output and threshold waveforms at 25 °C.
(Freq: 2.222 kHz)



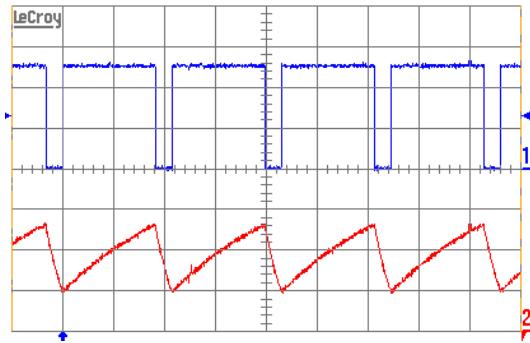
Output and threshold waveforms at 25 °C.
(Freq: 11.147 kHz)



Output and threshold waveforms at 200 °C.
(Freq: 1.575 kHz)

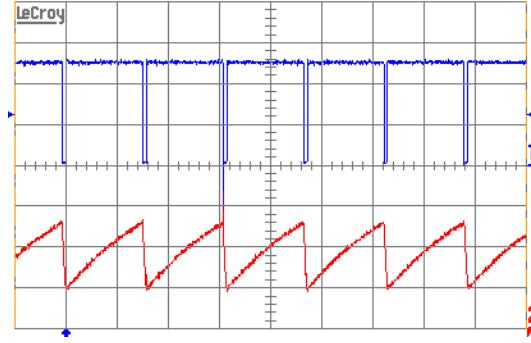


Output and threshold waveforms at 200 °C.
(Freq: 8.841 kHz)



Output and threshold waveforms at -190 °C.
(Freq: 4.649 kHz)

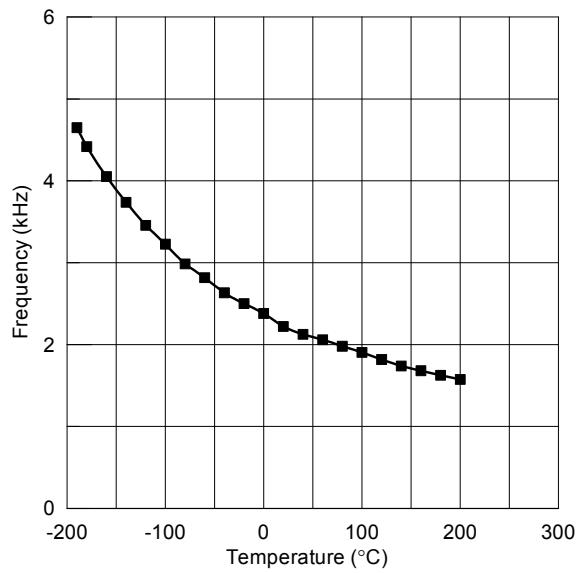
Astable Oscillator (Circuit 1)



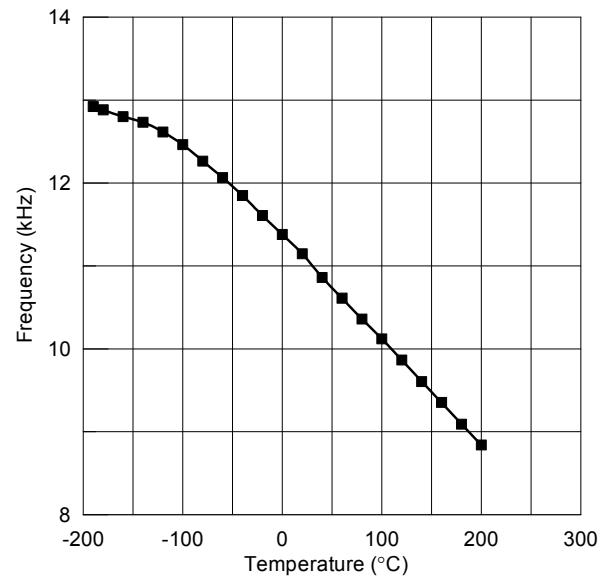
Output and threshold waveforms at -190 °C.
(Freq: 12.922 kHz)

Modified Circuit (Circuit 2)

Figure 4.—Output (top, blue) and threshold (bottom, red) signal waveforms for Circuits 1 and 2 at three temperatures prior to thermal cycling.

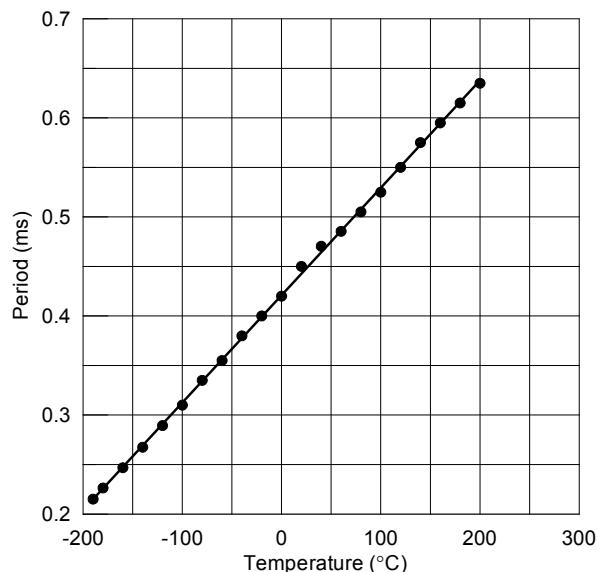


Circuit 1

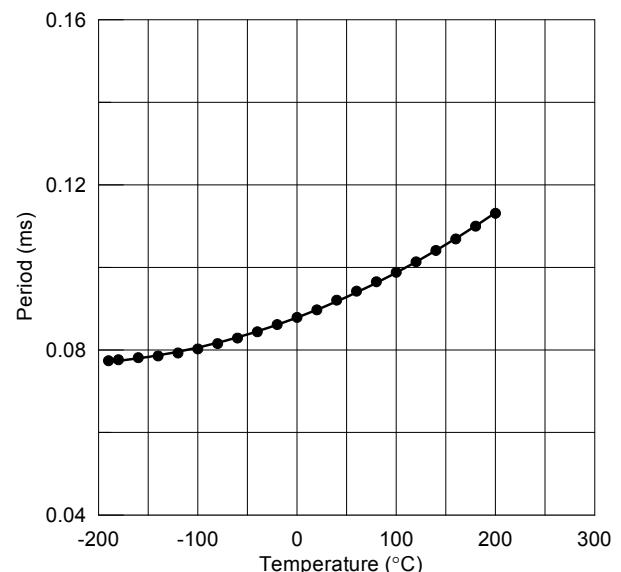


Circuit 2

Figure 5.—Output frequency versus temperature.

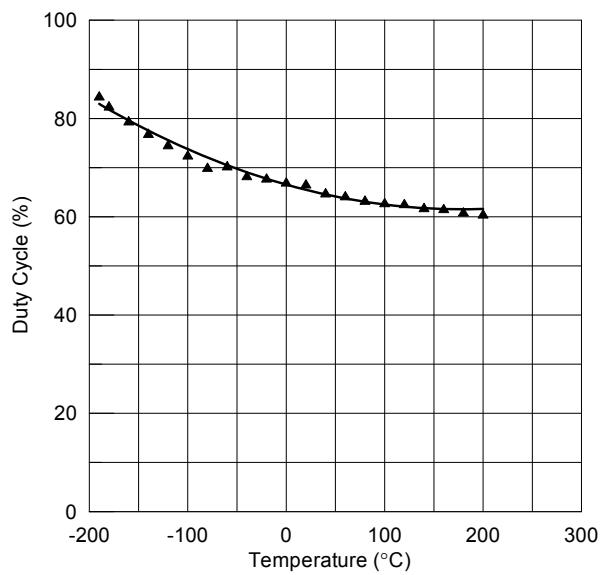


Circuit 1

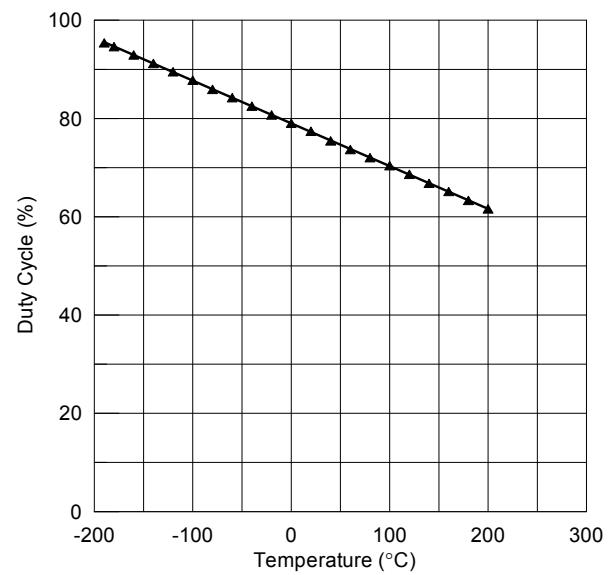


Circuit 2

Figure 6.—Period of the output signal as a function of temperature.

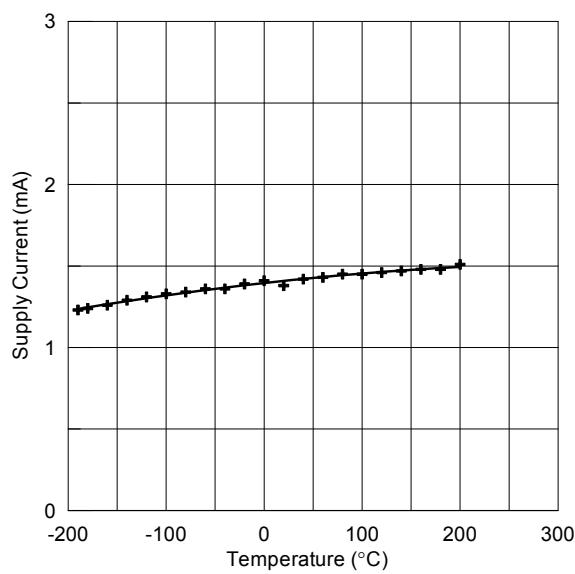


Circuit 1

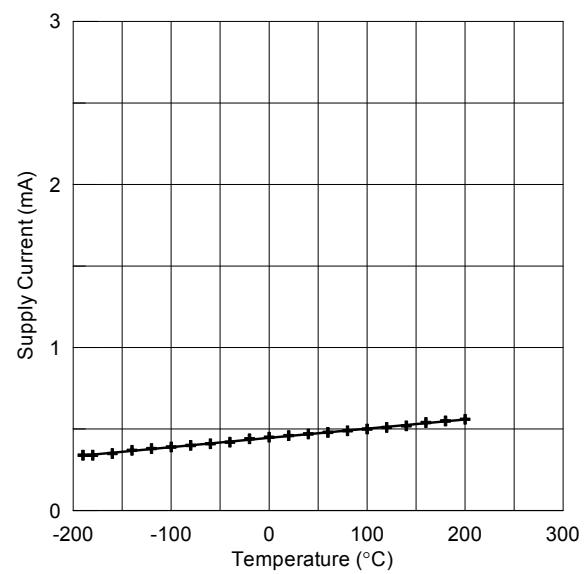


Circuit 2

Figure 7.—Duty cycle of output signal as a function of temperature.



Circuit 1



Circuit 2

Figure 8.—Circuit supply current as a function of temperature.

As previously stated, the performance of the oscillator circuits was also investigated after exposure to ten thermal cycles between 200 and –190 °C. Post-cycling measurements performed on all of the investigated parameters revealed no major deviation from those obtained prior to cycling at any given test temperature. In addition, no packaging damage was experienced by any the parts used in these circuits due to cycling. It is also important to point out that both circuits demonstrated successful start-up operation while at the extreme temperatures, i.e., 200 and –190 °C.

Conclusions

Two astable oscillator circuits utilizing a new silicon-on-insulator (SOI) 555 timer chip were investigated for potential use as a temperature sensor in extreme temperature environments. The circuits were designed to produce a stream of rectangular pulses whose period was proportional to the sensed temperature. The two circuits, which differed slightly in configuration, were evaluated between –190 and 200 °C using a platinum RTD as the temperature-sensing element. The performance of each circuit was investigated in terms of temperature-sensing response, output signal duty cycle, and supply current at various test temperatures before and after exposure to thermal cycling in the temperature range of –190 to 200 °C. Both circuits performed well throughout this temperature range in producing a pulse train whose period was proportional to the sensed temperature, and no major changes were observed in their power requirements as a result of either exposure to extreme temperatures or thermal cycling. In addition, all of the individual parts utilized in both circuits exhibited no physical or packaging damage. These results indicate that the circuits have the potential for use as temperature sensors over wide temperature range from jet engine environment to space exploration missions. Further testing, however, is required to determine operation performance and reliability under long-term exposure to extreme temperatures, thermal cycling, and other operational requirements.

References

1. Cissoid Company, “CHT 555 High Temperature Precision Timer,” Datasheet Doc. DS-07006 Rev. A, March 28, 2007.

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